EFFECTS OF POLYURETHANE FOAM SYSTEMS ON WIRING AMPACITY

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Polyurethane foam insulation systems represent an attempt to do away with some of the drawbacks of fiberglass batt insulation for ceilings and walls. The advantages of foam, relative to fiberglass, include lower labor costs, ease of handling, and less worry about inhalation of fiberglass by workers. Other attractive properties, per manufacturing data sheets, include reduced sound transmission, good fill around boxes and pipes, and a lack of urea formaldehyde that was present in some prior foam systems. These qualities, while admirable, are secondary in our mind to the important feature—*high R value.* (For the reader not familiar with energy management and heat transfer, the *R value* is defined as the *reciprocal of heat conductance—U*. Typical R values per inch thickness are: cellulose—3.7; fiberglass—3.3; polyicynene foams—3.6; and polyurethane foams—5.6[1]. A good "insulator" is by definition, a poor conductor of heat and will have a *high R value.*)

These foam systems, while serving as excellent thermal insulators, also have the potential for reducing the ampacity of type NM *(NM, per the National Electric Code, is Non Metallic, often generically referred to as "Romex")* cables, should the cables be thermally insulated with the foam. Tests were conducted by the authors to determine, if indeed, the ampacity of a wire was substantially reduced such that a fire situation could arise. Our findings are detailed here.

By way of background, the authors set out on this project after investigating a small fire caused by a light fixture in a newly built 17,000 S.F. mansion, under construction for 2 years. During the investigation, we noted that foam encased type NM in the residence was discolored and slightly charred in places, and yet the house had not been lived in. The manufacturer and distributor were contacted, and they denied there was a problem. The authors were told that the foam system had been tested by UL, and that there was no danger in using the foam. We were further told that no one ever uses 100 percent of the ampacity on wiring, and that even if the wire does fail, the foam will not allow a flame that might develop to be sustained.

Ampacity

The ampacity of a wire is actually its *amperage capacity*, as defined by the NEC. In general, cables sized at 14, 12, and 10, American Wire Gauge *(AWG)* and of NM construction[1] must be protected by overcurrent devices rated at 15, 20, and 30 amperes[2].

A characteristic of type NM cable, as with many electrical conductors, is that it can carry twice its rated current with no adverse short term effects. It is only when the cable carries 2.5 to 3 times its rating that a cable starts to become severely damaged. As an example, in open air (25°C) a 12 AWG cable of type NM can carry 40 amperes without significant overheating. At the 50 and 60 ampere level, however, we are reaching an area where sustained operation can cause significant damage and a possible fire. The damage starts with the melting of insulation, and can eventually lead to arcing.

In order to protect the cable, the NEC requires overcurrent devices. Commonly, these are circuit breakers. Contrary to anecdotal tales, a 20 ampere breaker does not trip when 20 amperes is marginally exceeded[3]. Rather, the breaker works in an inverse time—current fashion. As the current through a breaker increases, the breaker trip time decreases. Per UL 489 and NEMA AB-1, the following trip times are allowable for 15, 20, and 30 ampere breakers[4,5]:

TABLE1
Allowable trip time for 15, 20 & 30A breakers

CURRENT LEVEL	TRIP TIME MAXIMUM
135%	1 HOUR
200%	120 SECONDS

Thus, a 20 ampere breaker at 27 amperes must trip in 1 hour or less, and at 40 amperes it must trip in less than 120 seconds. Note that at the 24 ampere level (as an example), there is no requirement that the breaker ever trip in a normal, 25°C atmosphere[2]. From our discussions above, the 20 ampere cable will normally not be damaged until the current is at 50 or 60 amperes. Ergo, a 12 AWG cable that carries 24 amperes should never be damaged.

In regards to the NEC and overcurrent protection, the underlying theory is that a breaker (overcurrent device) must always trip before the temperature rating of a wire or cable is exceeded[6]. If the rating (often 75°C or 90°C) is not exceeded, the cable is presumed to be able to carry that current into infinity. Once the temperature rating is exceeded, there is a chance for a breakdown of the cable insulation, with resultant arcing and a possible fire. It is doubtful that a type NM cable will start to immediately degrade once the 75°C or 90°C threshold is exceeded. However, operation of the cable at temperatures sufficiently above the limits will erode the margins of safety built into the cable.

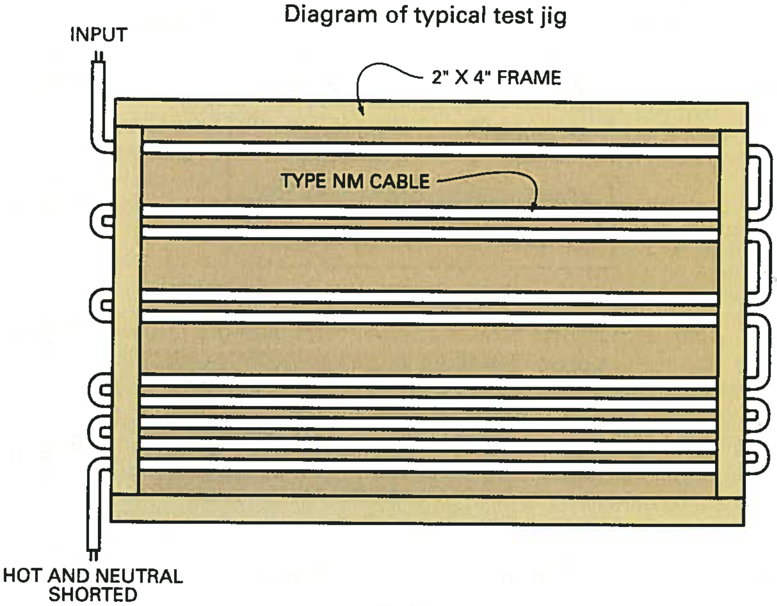
Testing

Much of the data we know about electrical cables is derived from work done at ambient temperatures, and with heat dissipation into free air. In a closed wall space with no insulation, this assumption is fairly valid. The question has to be raised, however, as to whether urethane foam thermal insulation systems seriously degrade ampacities of wires such that they can operate dangerously[3,4]. The foam insulation, when installed, clings to any cables that are present, forming a very intimate seal and preventing good heat dissipation.

Initial testing by the authors was conducted on both #12 and #14 AWG type NM cables, in that these cables are the most commonly used. Test panels were constructed using standard framing lumber and

1/4" plywood. The test cells used nominal 4" wall studs, and were each 4' in height and 30" in width. Testing was conducted at various current levels. We tested for both single and multiple wire runs (parallel cables tie wrapped together). Figure 1 shows a diagram of the test jigs that were used. Thermal insulation of an expanding foam type (polyurethane) was injected in all of the wall cavities and allowed to stabilize before testing. The type NM tested was rated at 90°C. Type K 30

FIGURE 1
Diagram of typical test jig



AWG thermocouples, feeding a Stanford Research 1630 scanner, were used to determine temperature on the outer jacket. Current was provided by a constant current power supply (DC). Using low voltage DC (8 volts maximum) allows the current levels to be precisely controlled. Because heat is a function of only current and resistance, heating effects between AC and DC are equal. Current entered a hot lead, ran to the other end of the fixture where hot and neutral were shorted, and then returned via neutral. Ambient temperature was 25°C for the testing. Photo 1 shows a test jig before insulation is injected.

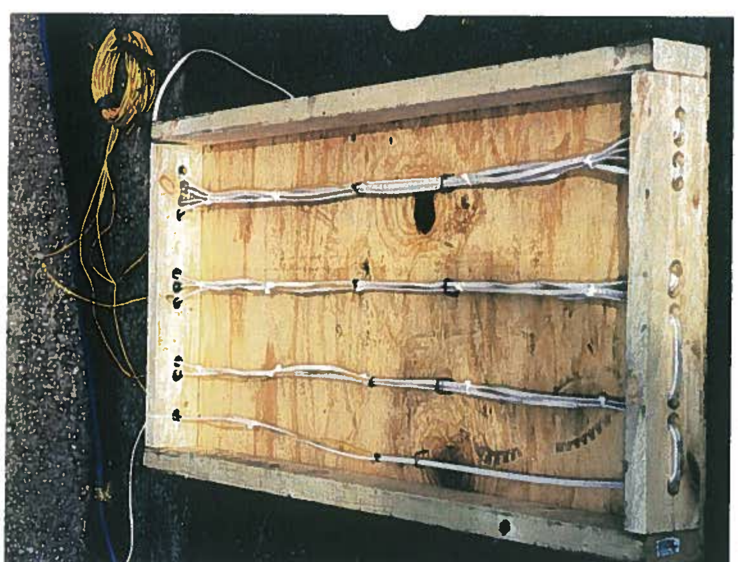


PHOTO 1—Test panels were constructed using standard framing lumber and 1/4" plywood. Initial testing was conducted on both #12 and #14 AWG type NM cables. Photo shows a test jig before the insulation was injected.

The same experiment was repeated on 12 AWG wire loaded at the 24 ampere level, with 4" (nominal) batt insulation. These results are also charted.

Chart 1 shows the temperatures obtained on the conductors after 6 hours. The data also shows what temperatures were present when the cavities had no insulation present.

CHART 1
Temperature obtained on conductor after 6 hours

AWG	NUMBER OF RUNS	CURRENT LEVEL	INSULATED	MAXIMUM TEMP (°C)
14	1	15	YES	173
14	2	15	YES	245
14	3	15	YES	294
14	4	15	YES	332
14	1	18	YES	195
14	2	18	YES	308
14	3	18	YES	390
14	4	18	YES	417
12	1	20	YES	236
12	2	20	YES	267
12	3	20	YES	265*
12	4	20	YES	290
12	1	24	NO	114
12	2	24	NO	131
12	3	24	NO	141
12	4	24	NO	146
12	1	24	FIBERGLAS	131
12	2	24	FIBERGLAS	206
12	3	24	FIBERGLAS	211
12	4	24	FIBERGLAS	215

* Inspection revealed that the foam in expanding, pulled the thermocouple away from the outer jacket of the type NM.

Discussion

What is obvious from the testing that has been carried out is that the cables reach dangerous temperatures when covered with the foam. The more important observation, however, is that there is no overcurrent protection for these cables as they reach temperatures where they can be damaged. As noted earlier, overcurrent devices are to trip at the 135 percent level in 1 hour or less, and may never trip at the 120 percent level. The assumption in the NEC is that there is so much safety margin in the cable that sustained 120 percent current levels will never damage the cable; the effect of the foam has been to take away almost all of the safety margin. A second observation is that even at rated current, the cables are exceeding their temperature rating. Thus, wire rated at 20 amperes can no longer safely carry 20 amperes.

A report from UL Canada was produced by a manufacturer, and it shows that wiring does exceed its temperature rating when tested in single runs at rated current (20 amperes—12 AWG and 15 amperes—14 AWG)[7]. Steady state temperatures of between 93 and 95°C were reached for both the 14 and 12 AWG cables. No testing was outlined in this report at the 120 percent or 135 percent levels. The manufacturer's claim that the insulating system had been tested by UL was, in essence, true, but the document produced in no way formed the basis for a UL listing; rather, UL only performed temperature testing on thermally insulated wiring.

While it is true that (per the NEC) branch circuits are not to be overloaded[8], the installing electrician has no control over what appliances a homeowner plugs into an outlet. Two resistances heaters, each rated at 1500 watts, will place a load of 25 amperes on the same branch circuit. At the 25 ampere level, the circuit breaker protecting this branch circuit (rated 20 amperes) cannot be counted on to trip.

Photo 2 shows the 14 AWG test jig that carried multiple runs and which was energized at the 18 ampere (120 percent) level. As one goes from 1 to 4 runs, the level of damage increases. With 3 and 4 runs, there is substantial charring of the insulation on the cable. Following the testing outlined for this test jig, we separated hot from neutral and then powered up the three conductors in the standard hot/neutral/ground configuration, as if the cable were in normal use. When powered at 120 VAC, arcing immediately occurred on the damaged cable.

PHOTO 2—The 14 AWG test jig carried multiple runs at 120 percent level. After the 3rd and 4th runs, there was substantial charring of the insulation on the cable. When powered at 120 VAC, arcing immediately occurred on the damaged cable.

Twelve AWG wire will always be hotter than 14 AWG wire, given the same current ratios. With 12 AWG wire, a 20 ampere current will dissipate .66 watts per foot, while 14 AWG wire will produce .59 watts per foot at the 15 ampere level (assuming 20°C ambient).

A final observation made by the authors relates to the manner in which fires occur. Fires often occur because margins of safety are eroded. While it is true that wires should not be overloaded, they often are. When these overload conditions develop, we count on the circuit breaker to remove current before damage occurs. The foam systems we have tested reduce the safety margin that is inherent in type NM cables.

Brochures from the foam system manufacturer that was tested list the R value for the foam tested at 5.3. In our opinion, the key factor in terms of heat entrapment is not just the R value, but also the manner in which the foam clings intimately with the cable. We should also note that we did not test every combination of current, wire size, and insulation type. Once a cable began to exceed ~194°F (90°C), no further testing was conducted at higher current settings.

The manufacturer of the foam system we tested has told these authors that fire initiation because of the foam is not an issue, because the foam will not allow oxygen to get to the "area of origin." They similarly state that the foam will not support combustion. We have not investigated the foam in terms of combustion, smoke production, UL 94 characteristics, or oxygen index. The authors plan additional work to determine in what manner, if any, the foam does contribute to a fire causation scenario. Our opinion, however, is that it would be much better for the wiring to never fail, as opposed to having a failed wire cease the combustion process because the atmosphere is oxygen deprived.

We also note that the failing insulation has the potential to produce a "ground neutral" fault, which in and of itself is not an immediate fire hazard. The NEC does state that there are to be no bonds between ground and neutral at any point but the service connection[9]. Should the wiring overheat from the foam insulation system and cause the neutral and ground to become "bonded", this section of the NEC has been violated. If a floating neutral scenario then occurs, this damaged branch circuit will try and "balance" the load to a residence, possibly bringing about a fire.

Design issues

The authors have been asked to formulate ways of protecting type NM cables that are already installed and insulated in existing houses. The best way that we have developed to protect existing foam installations is to derate the breaker and to make sure that the breaker is a GFI breaker. On 12 AWG wire, we believe that 15 amperes is the more appropriate size, with GFI protection. As has been shown by one of the authors [MEG], GFIs can cut off current in cables with failing insulation before a fire can occur[10].

Arc Fault Circuit Interrupters (AFCIs) are now on the market, and they have the potential to cut off power during arcing scenarios. In that this technology is new and has not been tested by the authors, we can state that this is only a potential solution.—*(continued next page)*

—About the authors

MARK GOODSON, PE—Mark Goodson graduated with a BSEE from Texas A&M in 1979. Graduate schooling was received in both forensic medicine and fire sciences. Since 1984, Mr. Goodson has operated Mark Goodson PE, specializing in the investigation of electrical and mechanical incidents. Mr. Goodson has taught numerous courses on technical aspects of fire investigation. He serves as an engineering consultant to numerous public sector agencies and Medical Examiner's Offices in Texas.

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KELLY COLWELL—Mr. Colwell has a degree in kinesiology from UNT. He is also licensed as a Master Electrician, and has been certified as an infrared thermographer. Mr. Colwell has completed post graduate work in Commercial Electrical Design and Fire Investigation. In addition to performing investigations regarding electrical fires, Mr. Colwell also performs infrared inspection for commercial and industrial clients.

Summation

It is our opinion that insulating foams have the ability to seriously degrade type NM cables. The extent of degradation will depend upon the level of loading and the duration of that loading. What we can state with certainty is that the foam can trap heat sufficiently such that the cables will exceed their maximum operating temperature and the overcurrent protection will not respond. In this regard, the presence of foam makes it necessary for the electrician to substantially derate any cables that it encases.

Footnotes:

1. *Values vary among manufacturers, trade associations and also, with fiberglass and cellulose, depend on settling.*
2. *While some 20 ampere breakers may trip at the 24 ampere level, one cannot count on this when designing an electrical system. The only known qualities are those supplied by the time-current curves from the manufacturer.*
3. *The term "dangerously" is meant to mean that the wire temperature exceeds its insulation rating.*
4. *For the purist, the NEC ampacity tables are even higher for 90°C insulation (per Table 310-16), but Article 336 states that type NM shall be considered as 60°C wiring, and 310-16 also mandates the lower breaker sizes.*

References:
[1] NFPA, National Electric Code, Article 336, 1996
[2] ibid, table 310-16
[3] Siemens, ITE Molded Case Circuit Breakers, TD 4944, 1992
[4] UL, Standards for Safety UL 489 Molded Case Circuit Breakers, 1996
[5] NEMA, Molded Case Circuit Breakers AB-1, 1992
[6] McGraw Hill, *NEC Handbook 19th Edition*, Article 240-1, 1987
[7] UL Canada, Report 4180, 1998
[8] NFPA, ibid, Article 210
[9] NFPA, ibid, Article 250
[10] IAAI, *Fire and Arson Investigator*, "GFIs and Fire Investigations," Jan., 1999

KNOW YOUR CERTIFICATION!

Did you know that there are different types of certifications for fire investigators?

MICHAEL A. SCHLATMAN, CFI–There are several different types of certification for the fire investigator. They include: local, state, provincial, national, and international certifications. There are also different requirements to obtain each certification. To confuse the issue further, each certification is accredited by different agencies.

In the spirit of informing our members of the newly discovered certifications available, however not the most rigorous to obtain, we are providing the following information.

The CFI Committee located a website, www.e-technologycenter.com, which is reportedly a career institute located in Tennessee. They offer courses in real estate, computer technology and law enforcement.

If you choose the **"LAW 303 Course Fire and Arson Investigation"** it will take you to a screen where, for $99.95 plus $19.95 for shipping and handling you can "Get Certified." But don't think that's all you have to do, there is the required reading of a provided e-book *Fire and Arson Scene Evidence: A Guide For Public Safety Personnel*. Reportedly in that book are forms from NFPA 906. There is no mention of NFPA 921, testing, or any other requirements. Nor does the site indicate where the "certification" is recognized.

In contrast, the IAAI Certified Fire Investigator (CFI) Certification is the only one that is internationally recognized. Countries such as Canada, Australia, New Zealand, Georgia and South Africa are participating in the IAAI CFI Program.

In addition, the IAAI CFI Certification is the only one accredited by the National Board on Fire Service Professional Qualifications. That accreditation is awarded due to the CFI program's administration, compliance with the duty areas in NFPA 1033, the requirements for education, experience, expert testimony (or stringent testimony classes) and training before the examination can even be taken.

So when you choose to become a certified fire investigator, please make sure you consider the requirements, the agency awarding the accreditation and where it will be recognized.

In our view, your choice is limited!

Amazing how stupid people can be!

When his .38-caliber revolver failed to fire at its intended victim during a holdup in Long Beach, California, robber James Elliot did something that can only inspire wonder: He peered down the barrel and tried the trigger again. Happily for most concerned, this time it worked. (Natural selection at its best!)

The chef at a hotel in Switzerland lost a finger in a meat cutting machine and, after a little hopping around, submitted a claim to his insurance company. The company, suspecting negligence, sent out one of its men to have a look for himself. He tried the machine out and lost a finger. The chef's claim was approved. (Too bad they didn't send a lawyer!)

Mourners at the funeral of Anna Bochinsky in Moinesti, Rumania, were naturally somewhat taken aback when she abruptly leapt from her coffin as it was being carried to the grave. Before they could react to this unexpected outburst, the woman bounded into the nearest road, where she was run over and killed by a passing car. (At least the coffin didn't go to waste)

A man who shoveled snow for an hour to clear a space for his car during a blizzard in Chicago returned with his vehicle to find a woman had taken the space. Understandably, he shot her dead. (Chivalry is dead!)

After stopping for drinks at an illegal bar, a Zimbabwean bus driver found that the 20 mental patients he was supposed to be transporting from Harare to Bulawayo had escaped. Not wanting to admit his incompetence, the driver went to a nearby bus-stop and offered everyone in the queue a free ride. He then delivered the passengers to the mental hospital, telling the staff that the patients were very excitable and prone to bizarre fantasies. The deception wasn't discovered for 3 days. (And the escapees became politicians?)

In Minneapolis, USA, 28 year-old Derrick L. Richardson has been charged with third-degree murder of his much loved cousin, Ken E. Richardson. According to local police, Derrick had suggested to Ken that they play a game of Russian Roulette, but, having no revolver, instead put a semiautomatic pistol to his cousin's head. Apparently, he did not realize that one bullet always loads into the firing chamber of a semiautomatic. (Guns don't kill people, stupidity kills people!)

An American teenager was in the hospital recovering from serious head wounds received from an oncoming train. When asked about how he received the injuries, the lad told police that he was simply trying to see how close he could get his head to a moving train before he was hit. (DUH!)